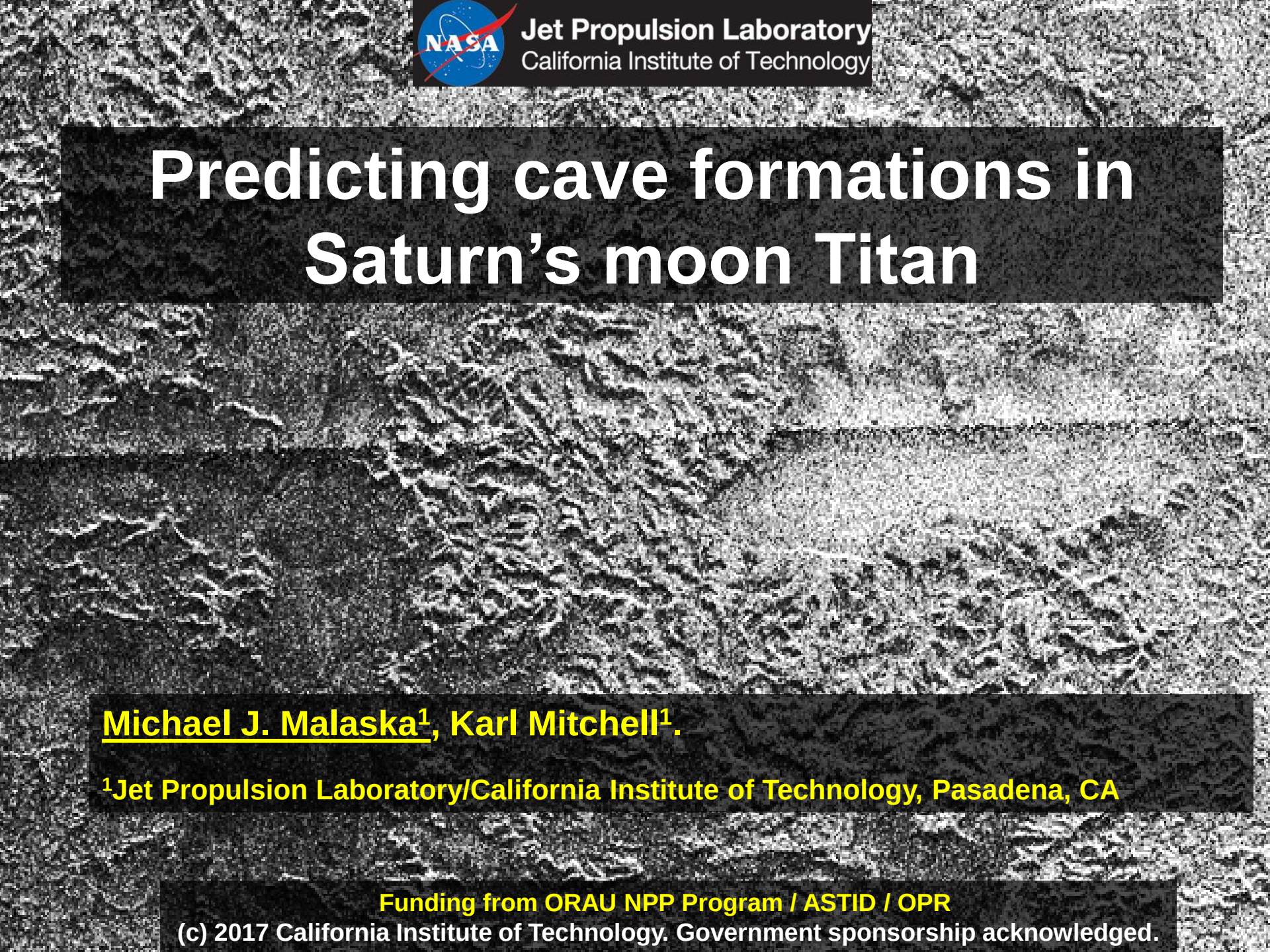


Jet Propulsion Laboratory
California Institute of Technology

Predicting cave formations in Saturn's moon Titan

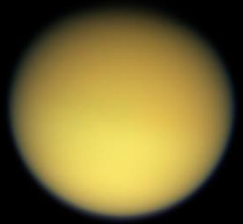
Michael J. Malaska[1], Karl Mitchell[1].

[1]Jet Propulsion Laboratory/California Institute of Technology, Pasadena, CA

Funding from ORAU NPP Program / ASTID / OPR

Fluids and materials

Earth (288 K)



Titan (94 K)

Fluids

H_2O

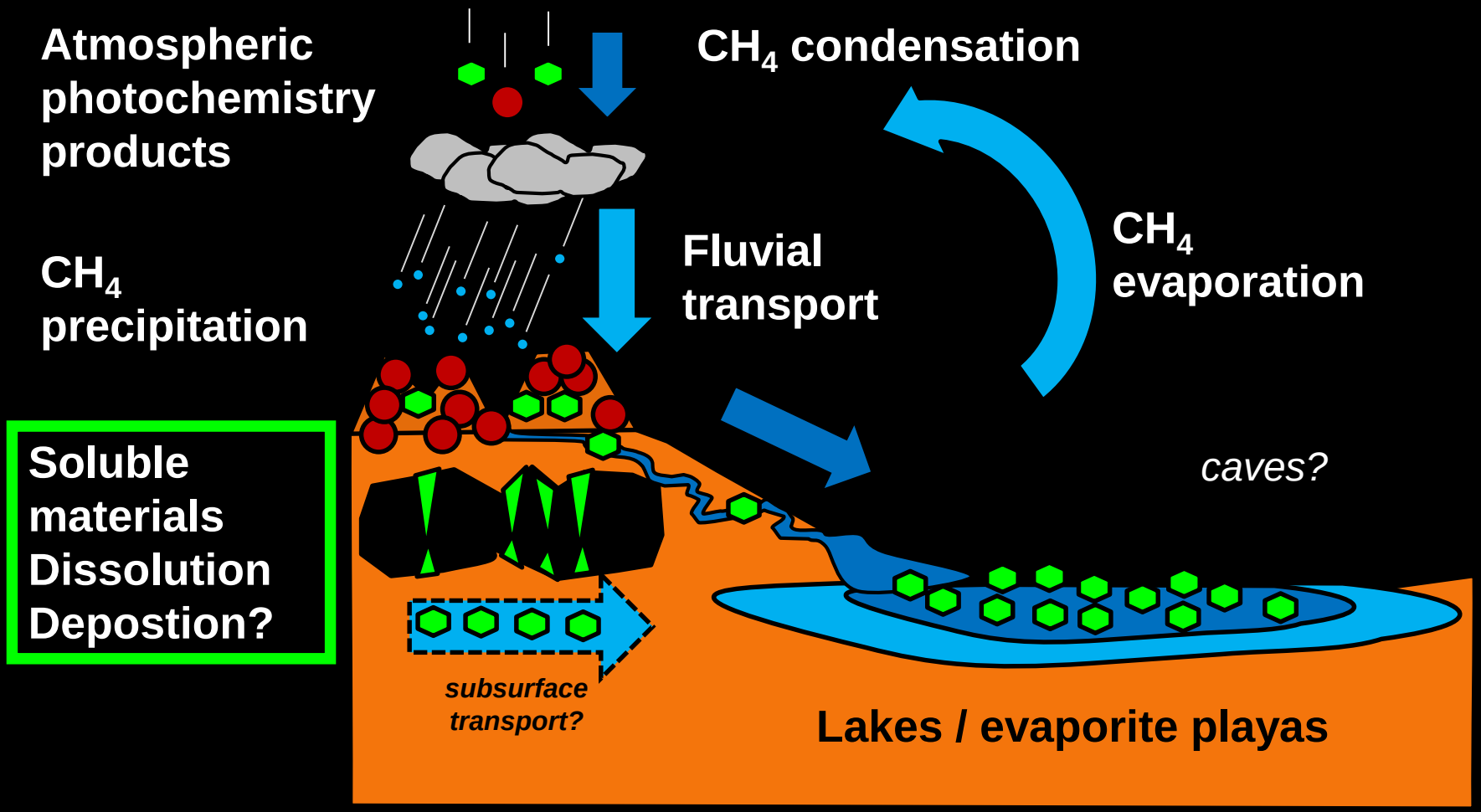
Methane (CH_4) / N_2
Ethane (C_2H_6)
Propane (C_3H_8)

Materials

Halite (NaCl)
Gypsum ($NaSO_4$)
Limestone ($CaCO_3$)
Dolomite ($CaMg(CO_3)_2$)
Quartz (SiO_2)

Ethylene (C_2H_4)
Acetylene (C_2H_2)
n-Butane (C_4H_{10})
1,3-Butadiene (C_4H_6)
Benzene (C_6H_6)
Acrylonitrile (CH_2CHCN)
Acetonitrile (CH_3CN)
Cyanoacetylene (HCCCN)

Titan Organic Cycle
Organics and CH_4



Malaska et al., Workshop on the Habitability of Icy Worlds (2014), Abstract 4020.

Cryogenic dissolution labwork
Solubilities in methane-ethane-nitrogen

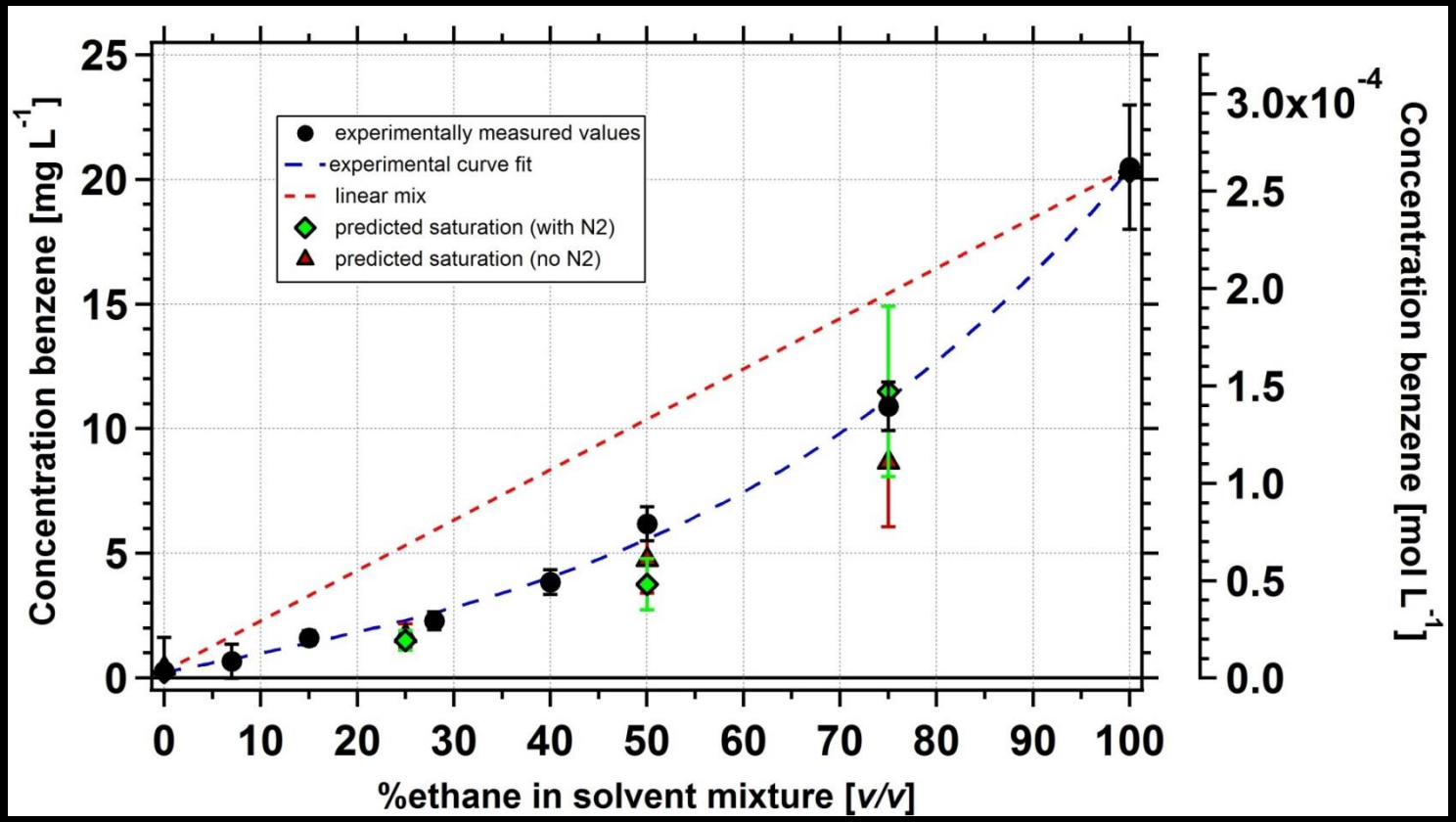
Malaska and Hodyss, LPSC 44 (2013), Abstract 2744.

(Image credit Mike Malaska)

Titan organics vs. Earth carbonate

Titan organics	Earth carbonate
Simple dissolution	Complex dissolution
No dissolved ion effect	Dissolved ion effects
No biology (?)	Microbe alteration
No pH effects (no pH)	pH effects
Multiple liquids possible	H_2O evaporation causes deposition
CH_4 evaporation→more aggressive!	
N_2 gas increase →deposition	CO_2 gas increase →aggressive dissolution

CH_4 methane is a poor solvent
C_2H_6 ethane is better



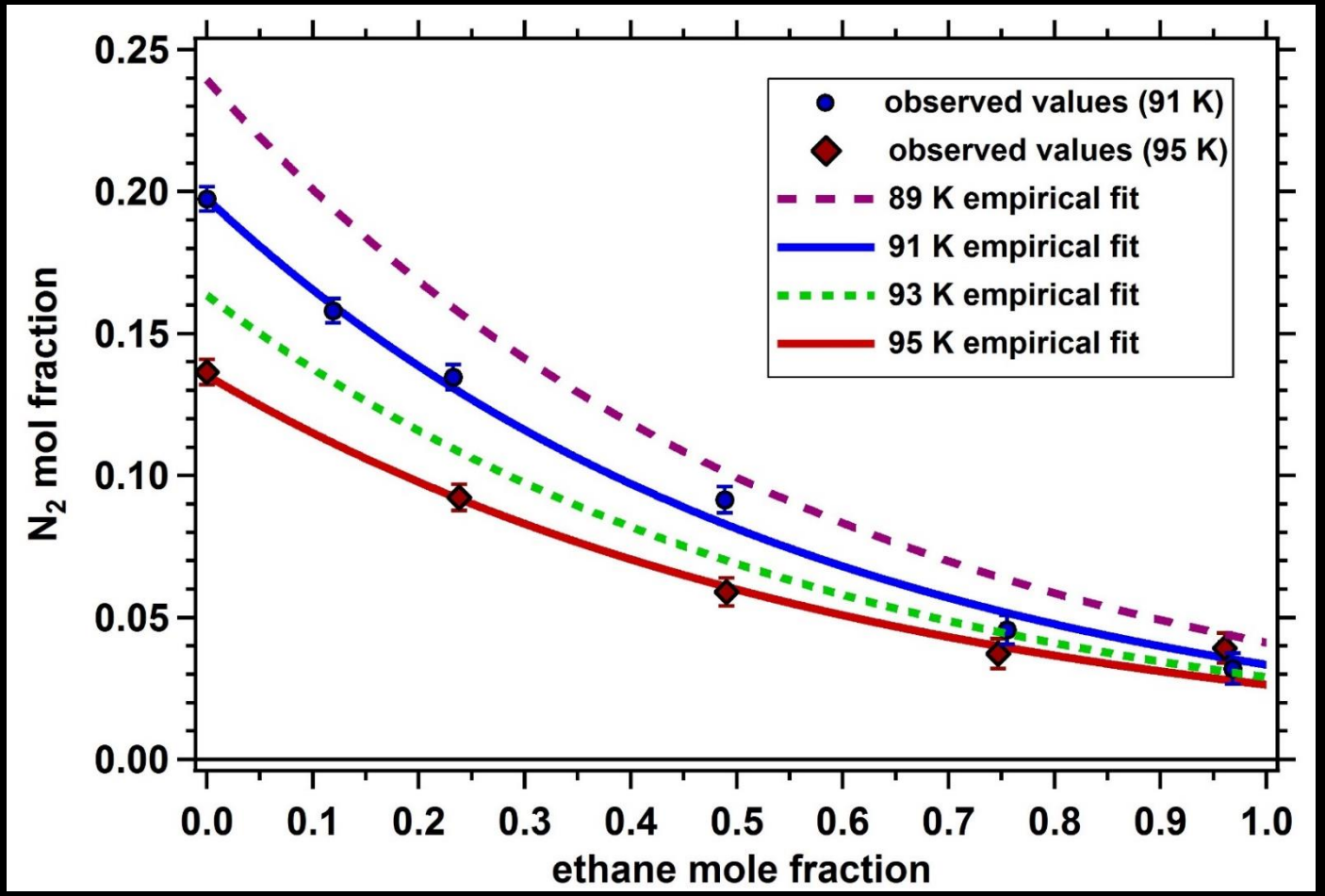
Solubility of benzene in methane-ethane
Removal of methane causes dissolution

Malaska et al., in preparation

N_2 (nitrogen) is a lousy solvent[1]

CH_4 (methane) loves N_2; C_2H_6 (ethane) does not

More CH_4, lower T, more pressure → More N_2 (bad)[2]



[1] Glein and Schock, Geochim et Cosmochim Acta 115 (2013) 217-240.

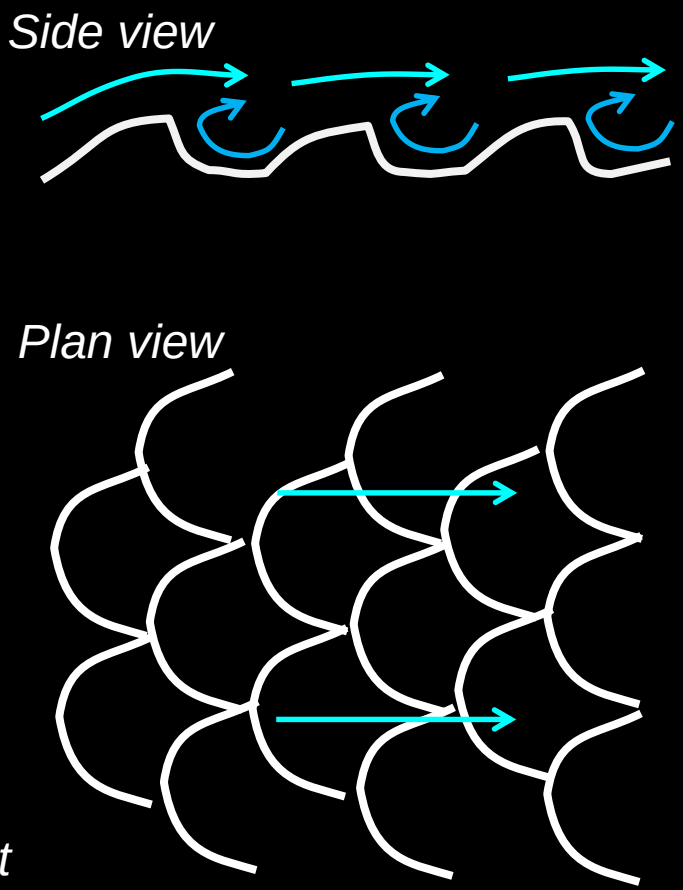
[2] Malaska et al., Icarus 289 (2017) 94-105.

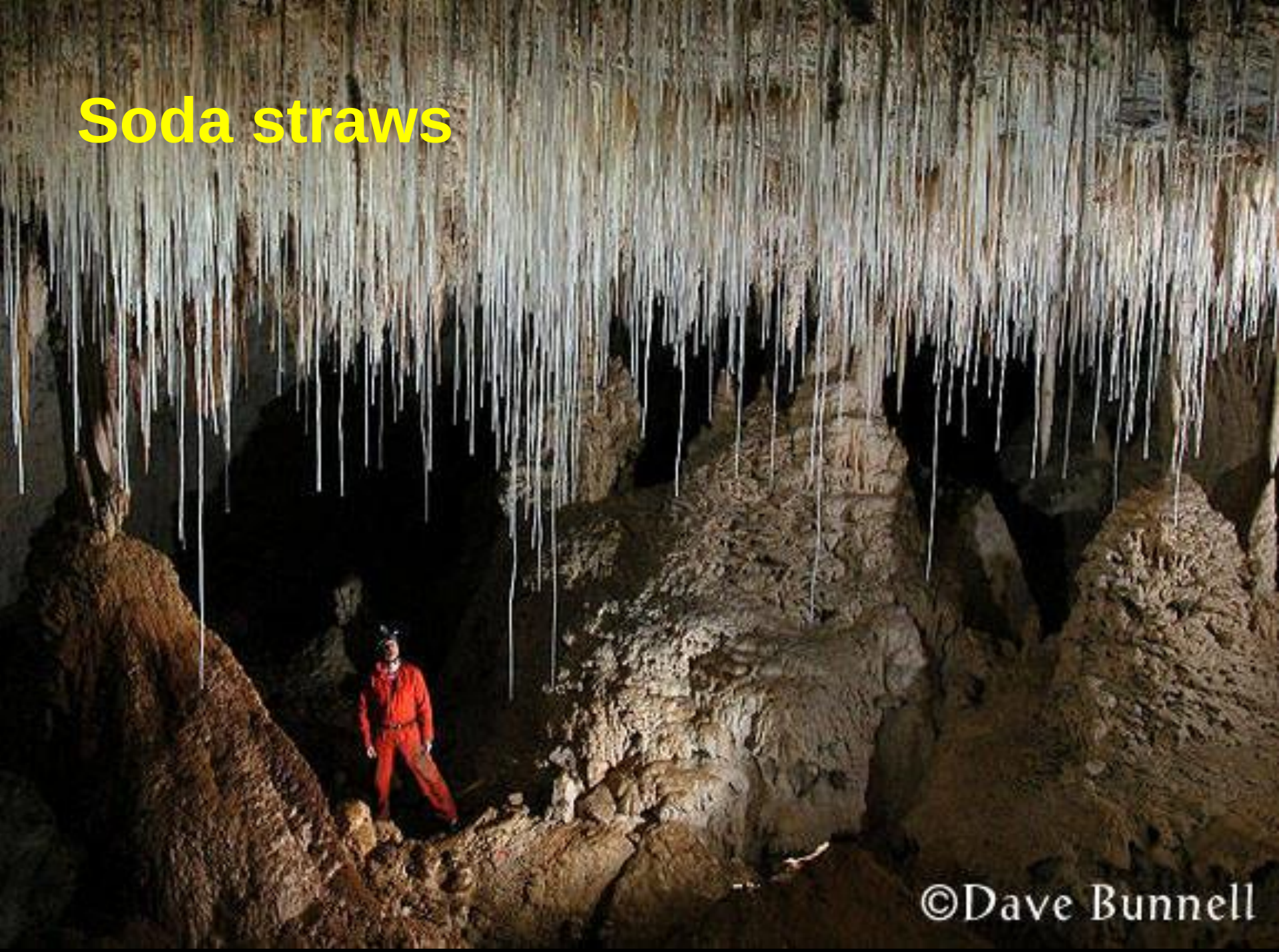
Aggressive dissolution	Saturation deposition
Add ethane (C_2H_6) or propane (C_3H_8)	Add CH_4/N_2
Add ethylene solid	
Mixed solvent evaporation (increases remnant C_2H_6)	Total complete evaporation
Add heat (→removes N_2)	Cool (→adds N_2)
Decrease pressure (removes N_2)	Increase pressure (adds N_2)

Predicted cave formations: Scalloping

Formed in limestone, gypsum, halite, dolomite on Earth
Same flow processes/regime should occur on Titan

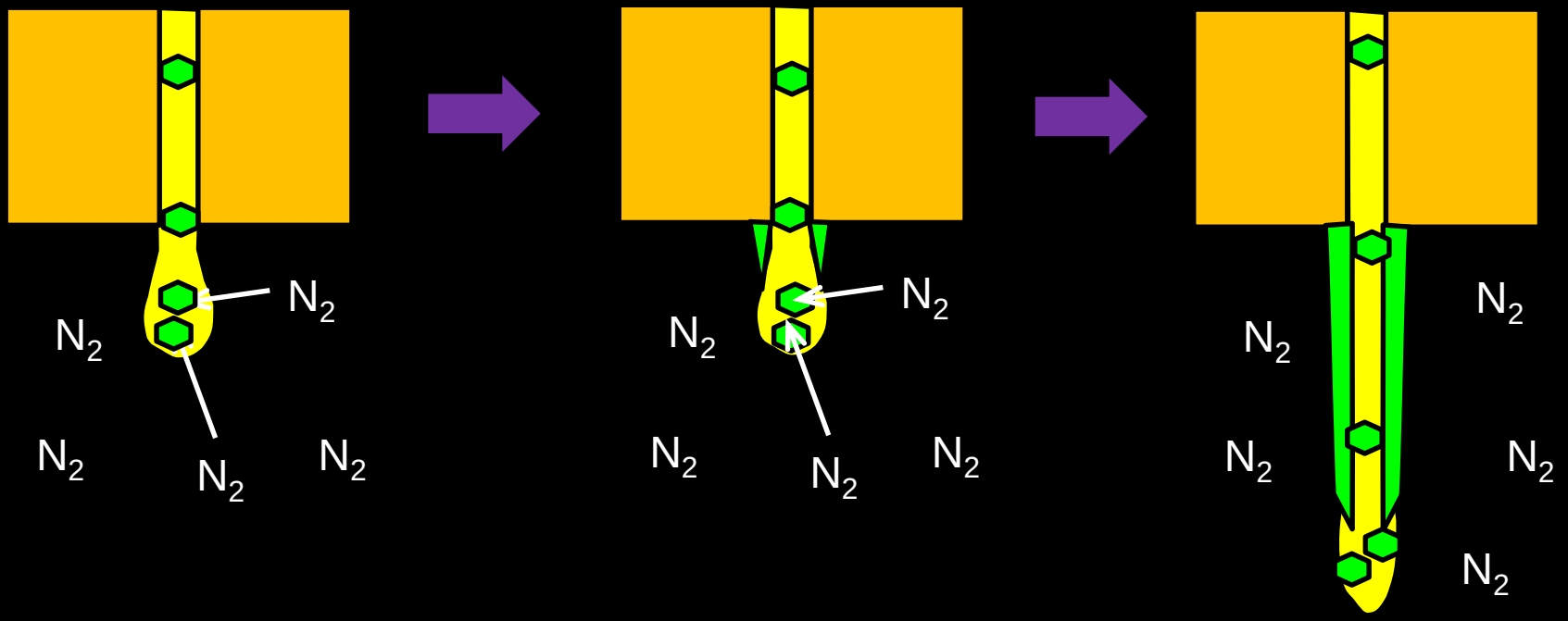
Scalloping in Parks Ranch cave gypsum conduit
Carlsbad, NM (w/ Aaron Curtis)




Soda straws
©Dave Bunnell

Predicted formations: Soda Straws 1

Inceased depth→more N_2→solubility drops→deposition



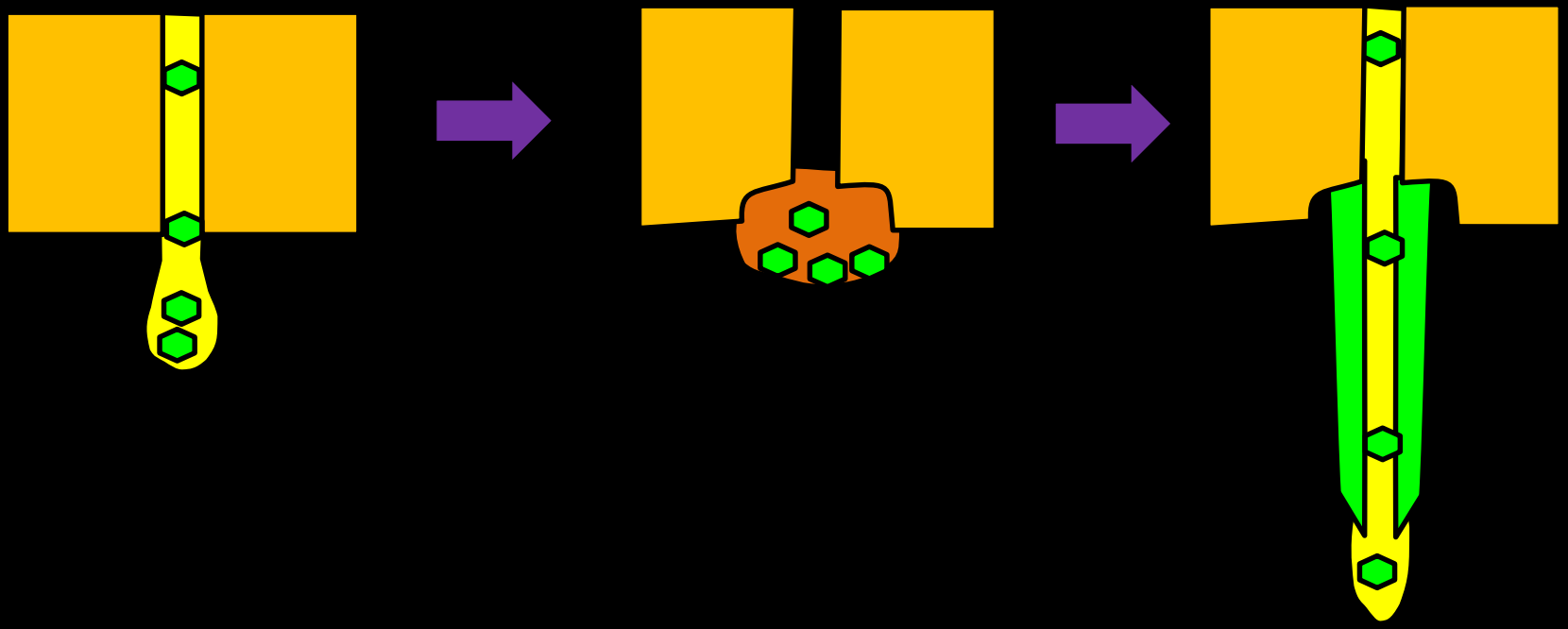
1. Higher N_2 pressure at depth

2. N_2 goes into solution. N_2 lowers solubility. Materials precipitate

3. Cycle repeats. Soda straw grows

Predicted formations: Soda Straws 2

Mixed solvent→C_2H_6 residue→CH_4 arrives→precipitation



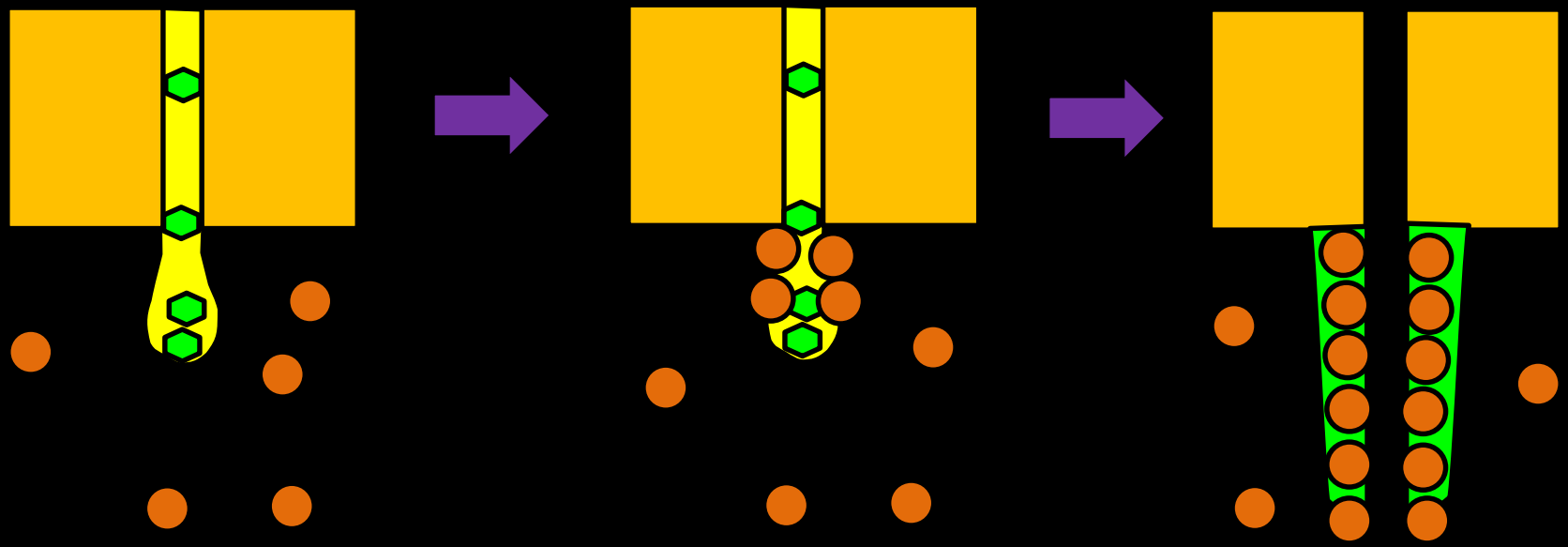
1. Mixed saturated CH_4/C_2H_6 liquid

2. CH_4 evaporates C_2H_6 residue aggressive

3. Saturated CH_4 arrives. Solubility drops. Excess precipitates on sides

Predicted formations: Soda Straws 3

Airborne particles→wetted by drops→evaporite cement



1. **Drop forms**

2. Haze/dust particles stick to droplet

3. Drop evaporates, cements particles.

Example of mud soda straws

Lava tube near Pisgah Crater, Mojave desert, CA

Image credit Mike Malaska 2016

Titan dissolved minerals are mixed

Deposition layers could be chemically complex
Could serve as marker for Titan chemical/climate history

Titan evaporite sequence:
Cordier et al., Icarus 270 (2016) 41-56.

Phase transitions of Titan materials:
Toumi et al., Icarus 270 (2016) 435-442

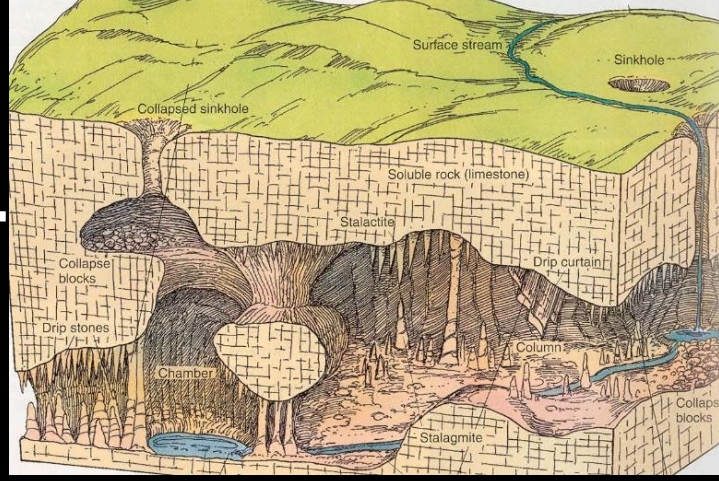
Titan co-crystals:
Vu et al., J. Phys. Chem. A 118 (2014) 4087–4094

Titan minerals:
Maynard-Casley et al., American Mineralogist, in revision.

Image credit: Montana Bureau of Mines and Geology / Rich Aram and Alan English
https://www.mbmg.mtech.edu/calendars/2016info.asp

Conclusions

Like Earth, but Titan-different…



Christopherson, 2003

Titan karst: cave formations likely

Organic dissolution/precipitation equilibria

Mixed and complex hydrocarbon\nitrogen liquids

Mixed and complex organic chemical/structural deposits
→ pure crystals throughout not likely

Compare/contrast with Earth non-limestone features
Scalloping likely in conduits
Soda straws have multiple modes of formation